LMC X-1 AND LMC X-3 AS SEEN BY RXTE

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ABSTRACT LMC X-1 and LMC X-3 are the only two black holes that are consistently seen in the soft X-ray state. We present the results from the spectral and temporal analysis of a long (150 ksec) observation of these two objects. The spectra can be well described by a disk black body plus a high energy power-law, which extends to at least 50 keV.

Starting in December 1996 we have also monitored these objects with RXTE in about three to four week intervals. We present the evolution of the spectral parameters of the sources from the first twenty pointings. LMC X-1 has a very stable spectrum and does not exhibit any large scale variability. On the other hand, the appearance of LMC X-3 changes considerably over its 200 d long cycle. This variability can either be explained by periodic changes in the mass transfer rate or by a precessing accretion disk analogous to Her X-1.

KEYWORDS: galactic black holes; LMC X-1; LMC X-3.

1. INTRODUCTION

Galactic black holes (BHs) reveal a large variety of states, which are characterized by their distinct spectral shapes and temporal behaviors. The most important states which have been identified are the so called "hard state", which is characterized by a hard X-ray spectrum with a photon index $\Gamma = 1.7$ and large variability (rms = 30%), and the "soft state", which is spectrally softer ($\Gamma \sim 2.5$) and characterized by less variability. Although the soft state is very common in galactic BHs, most observational attention has been concentrated on the hard state, since most of the brighter galactic BHs are found in this state and only show occasional state switches to the soft state. Only two of the persistent galactic BHs, LMC X-1 and LMC X-3, are always found in the soft state. *Ginga* observations revealed that both sources exhibit very interesting physical behavior, such as a possible low-frequency QPO and long term spectral variability (Ebisawa et al., 1991, 1993).

To enable a systematic study of the soft state we have monitored LMC X-1 and LMC X-3 with the Rossi X-ray Timing Explorer (RXTE) since the end of 1996 in three to four weekly intervals. To facilitate the understanding of the spectrum, the campaign started with 170 ksec long observations of both sources. In this paper we present first results from the spectral analysis of the long observations. These results are based on an analysis of the Proportional Counter Array (PCA) data
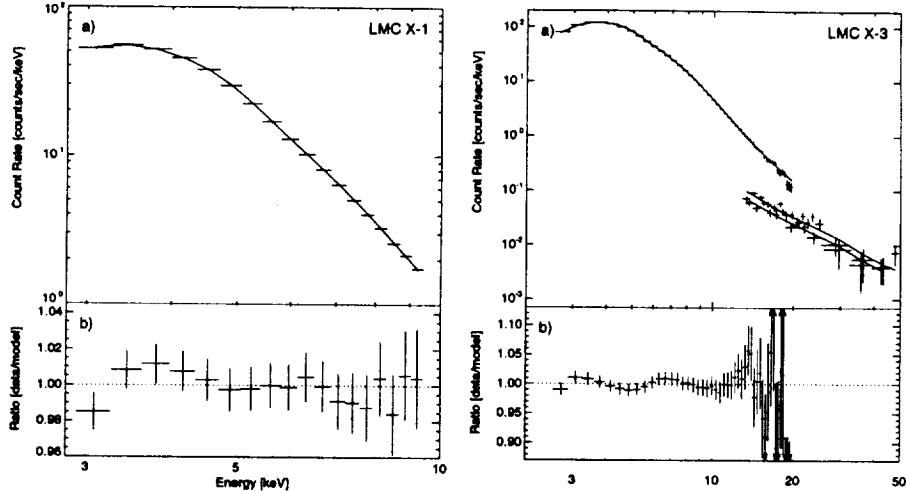
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FIGURE 1. RXTE spectra of LMC X-1 (left) and LMC X-3 (right) *a* PCA and HEXTE spectra. *b* Ratio between the data and the best fit disk black body spectral model.

as well as the High Energy X-ray Timing Experiment (HEXTE) data. We used the standard RXTE data analysis software, ftools 3.5. Spectral modeling was done using XSPEC, version 10.00s. The instruments are described in more detail by Jahoda et al. (1997) and Rothschild et al. (1998). Our data analysis methodology is basically the same as used by us before (Dove et al., 1998). See Wilms et al. (1998) for a more detailed description of the data and data analysis.

2. LMC X-1 AND LMC X-3: THE LONG OBSERVATIONS

In Fig. 1 we show the RXTE spectra measured during the long observations of LMC X-1 and LMC X-3 in 1996 December. Both spectra can be well described by a multicolor disk blackbody (MCD) to which a high energy power-law is added. The multicolor disk black body is an approximation to the spectrum of an accretion disk with $T(r) \propto r^{-3/4}$, i.e., a simple α-disk (Mitsuda et al., 1984). For LMC X-1, the PCA spectrum from 2.5 to 10 keV can be described by a MCD model with $kT_{in} = 1^{+0.02}_{-0.04}$ keV. The high energy power-law has a photon index $\Gamma = 3.65^{+0.05}_{-0.07}$. Due to its larger luminosity, LMC X-3 is detected over a much larger energy range, up to 50 keV with HEXTE. This is the highest energy at which LMC X-3 has ever been observed. In agreement with previous observations, the joint PCA/HEXTE data can be described by a multicolor disk black-body with $kT_{in} = 1.25 \pm 0.01$ keV plus a power-law with a photon-index of $\Gamma = 2.5 \pm 0.2$ ($\chi^2/\text{dof} = 114/117$).

When the data are fitted with the MCD plus power-law model, the residua show a characteristic feature in the region around 7.5 keV for both objects. Similar features have been seen previously in LMC X-1 by *Ginga* and *BBRXT* (Schlegel et al., 1994; Ebisawa et al., 1991, and references therein). These investigations showed that formally a better χ^2_{red} could be obtained by the introduction of a
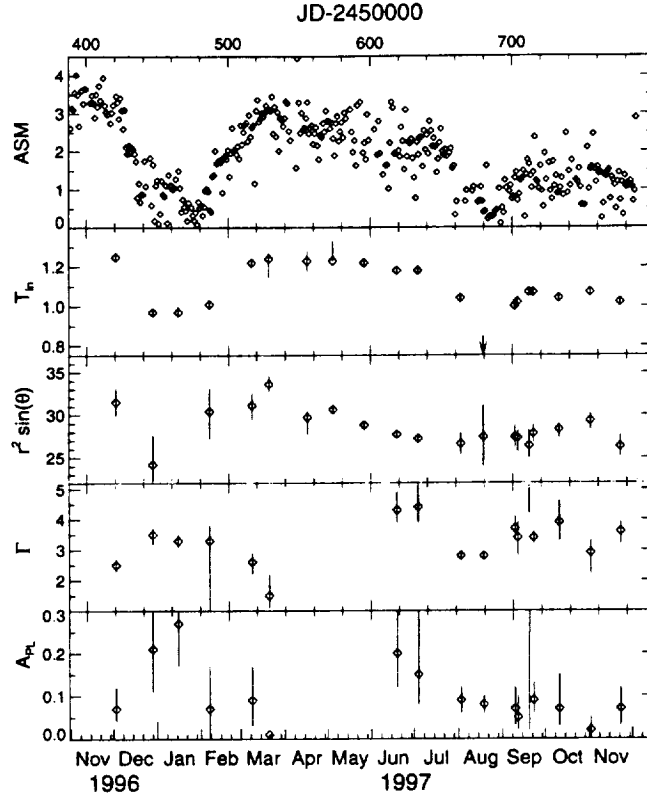
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FIGURE 2 *Top:* RXTE/ASM soft X-ray flux, illustrating the long term variability. *Following Plots:* Temporal variability of the best-fit parameters for the first 20 monitoring observations, T_{in}: inner disk temperature in the multicolor disk model (keV), $r^2 \sin \theta$: normalization of the MCD model, Γ: photon index of the high energy power-law, A_{PL}: Normalization of the power-law (photon flux at 1 keV).

smeared iron edge feature. In our data, the remaining calibration uncertainty of the PCA response matrix prohibits any statement whether the improvement in χ^2 is real. We caution, however, that the region around 7.5 keV is the region where the high energy power-law and the MCD do contribute similar amounts of flux to the model spectrum. Therefore, the "edge" might be just a feature associated with this region of overlap. Since this transitional region appears to be important for the full understanding of the soft state, we are planning to self consistently model the soft state spectrum using a Monte Carlo Comptonization code which will produce the correct Comptonization spectrum even when the seed photon energy is similar to the electron energy.

3. LMC X-3: SPECTRAL VARIABILITY

We used the MCD plus power-law model to describe the data from our 10 ksec long monitoring observations measured in 1997. The results of this modeling are shown in Fig. 2. For the first part of the observations until 1997 May, lower MCD temperatures are associated with softer high energy power-laws. During the second half of the observations, the correlation between the hard and soft component is less clear. This could indicate that the soft and hard spectral components, which we associate with the accretion disk and a Comptonizing corona as most plausible places of origin, are produced in geometrically separate regions of the system. We will be able to test this claim with the data from the second year of observations which are currently being measured.

It is interesting to note that the possible change in the behavior of the soft and the hard spectral components might be associated with a change in the long term variability of LMC X-3. As we show elsewhere (Wilms et al., 1998), the RXTE All Sky Monitor (ASM) data for 1996 and the first part of 1997 clearly show the pure ~ 200 d sinusoidal periodicity previously seen by Cowley et al. (1991). Since the second half of 1997, however, this variation has been replaced by a more complicated pattern, which is much less periodic and does not show the 200 d periodicity. If the variability is interpreted as being due to accretion disk precession similar to that of Her X-1 (Schandl, 1996; Maloney et al., 1996), this change might indicate a change in the accretion disk geometry. If this is the case, our spectral data could help in clarifying this phenomenon.

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